Site-selective magnetization measurements using nuclear resonant scattering

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Nuclear resonant scattering of synchrotron radiation is a relatively new tool to study magnetization properties via the hyperfine interactions [1-3]. It has the advantage of being isotope-selective, which makes it extremely suitable for depth-resolved or layer-resolved magnetization measurements. With the incident synchrotron radiation being linearly polarized, the nuclear resonant scattering process is sensitive to the magnitude and the 'absolute' orientation of the magnetization vector. The sign of the magnetization vector, however, cannot be measured. To overcome this limitation, we introduced the use of circularly polarized x-rays in nuclear resonant scattering and demonstrated that in this case the scattering process is also sensitive to the sign of the magnetization vector [4]. Now the full magnetization information is accessible and one can record isotope-selective magnetization curves that reflect only the magnetic properties of specific parts of the sample. This approach, called nuclear resonant magnetometry, is ideally suited for the study of magnetic thin films and multilayers. To illustrate this, we applied it to interlayer-coupled Fe/Cr(100) multilayers.

The investigated samples are epitaxial Fe(50Å)/Cr(11Å)/Fe(50Å)/Cr(11Å)/Fe(50Å) quintalayers for which a strong antiferromagnetic interlayer coupling is expected. When placed in a large external field applied along the easy axis, the magnetic moments in all three Fe layers will be aligned with the field. With decreasing fields, the outer moments will remain close to the field direction, while the moments in the central Fe layer are expected to rotate to the opposite direction due to the interlayer coupling. Thus, by selectively recording the magnetization curve of the central Fe layer, one can study the interlayer coupling in a very direct way. Therefore, the quintalayers were made such that the two outer layers consist of a non-resonant iron isotope, while the central layer consists of the nuclear resonant isotope ^{57}Fe. This isotopic enrichment has no influence on the electric or magnetic properties of the quintalayer, but it does permit to measure the magnetic response of the central Fe layer selectively with nuclear resonant magnetometry.

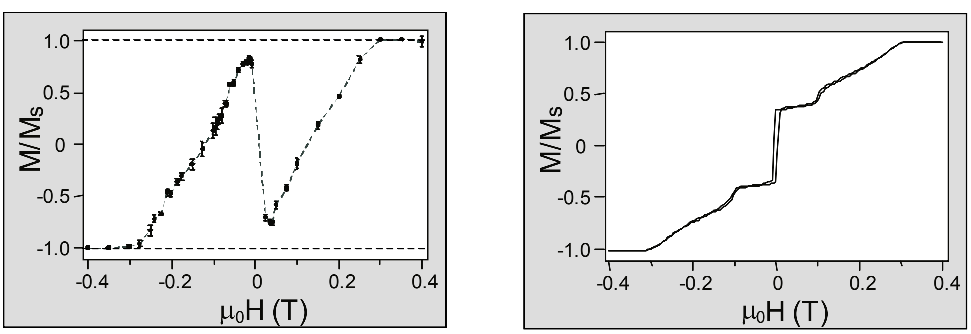

Figure 1: Magnetization curves of the sputtered Fe/Cr quintalayer with the external field along the easy axis. Left: nuclear resonant magnetometry measurement showing the response of only the central Fe layer. Right: macroscopic measurement showing the response of all three Fe layers.

We compared samples produced either by dc magnetron sputtering or by molecular beam epitaxy. We found that for samples made with dc magnetron sputtering the central magnetization vector at zero field is not completely opposite to the field direction as would be expected for a purely antiferromagnetic quintalayer. This deviation is obvious from the nuclear resonant magnetometry curve in figure 1, since the magnetization at zero field deviates from the saturation value. In order to get more quantitative information on the interlayer coupling angle, the nuclear resonant magnetization curve is combined with the macroscopic magnetization curve, also shown in figure 2. This way, the angle between the manetization vectors in the subsequent Fe layers could be determined as a function of the external field strength. The result is shown in figure 2. At zero field we found an angle of 162(4)º [4]. By comparison with MBE-grown samples where this deviation from 180º alignment was absent, we could attribute the existence of non-collinear coupling to extrinsic properties of the multilayer which are determined by the preparation conditions.

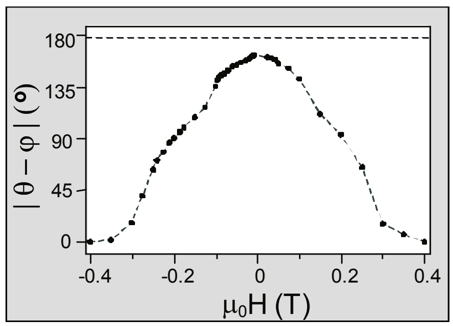

Figure 2: Interlayer coupling angle in the sputtered Fe/Cr quintalayer with the external field along the easy axis. θ–φ is the angle between the magnetization vectors in the outer Fe layers and the magnetization vector in the central Fe layer.

The present example illustrates how nuclear resonant magnetometry can provide very detailed and quantitative magnetic information. This can lead to a more profound understanding of magnetism in thin films and multilayers. Also smaller entities, like monolayers [1] or nanoscale islands [5], can be studied with nuclear resonant scattering of synchrotron radiation. Therefore, we believe that nuclear resonant magnetometry can become a powerful technique to study small magnetic heterostructures, especially when site-selective information is desired.

References

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